Path planning algorithms benchmarking for grapevines pruning and monitoring *

Sandro Augusto Magalhães[1 [0000−0002−3095−197X]], Filipe Neves dos Santos[1 [0000−0002−8486−6113]], Rui Costa Martins[1 [0000−0001−9058−3147]], Luis F. Rocha[1 [0000−0002−8680−4290]], and José Brito[2]

[1] INESC TEC, Campus da FEUP, Rua Dr. Roberto Frias 4200-465 Porto Portugal `http://www.inesctec.com/`

[2] Faculty of Engineering of University of Porto, Rua Dr. Roberto Frias 4200-465 Porto Portugal `http://www.fe.up.pt/`

Abstract. Labour shortage is a reality in agriculture. Farmers are asking for solutions to automate agronomic tasks, such as monitoring, pruning, spraying, and harvesting. The automation of these tasks requires, most of the time, the use of robotic arms to mimic human arms capabilities. The current robotic arm based solutions available, both in the market and in the scientific sphere, have several limitations, such as, low-speed manipulation, the path planning algorithms are not aware of the requirements of the agricultural tasks (robotic motion and manipulation synchronisation), and require active perception tuning to the end-target point. This work benchmarks algorithms from open manipulation planning library (OMPL) considering a cost-effective six-degree freedom manipulator in a simulated vineyard. The OMPL planners shown a very low performance under demanding pruning tasks. The best and most promising results are performed and obtained by BiTRRT. However, further work is needed to increase its performance and reduce planning time. This benchmark work helps the reader to understand the limitations of each algorithm and when to use them.

Keywords: Agricultural robotics · robotic pruning · robotic manipulators.

1 Introduction

The strategic European research agenda for robotics [6] affirms that robots may improve agricultural efficiency and competitiveness.

Steep slope vineyards placed in the demarcated region of Portugal, UNESCO Heritage place, presents unique characteristics, as shown in Fig. 1, to produce Porto wine. These steep slope vineyards, like other agricultural scenarios, are labour intensive, as most of the required work is hands-on. Because of the

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frequent exposition of human workers to high temperatures, high demanding physical work, and non-ergonomic tasks, viticulturists are experiencing a critical labour shortage. So, naturally, and to overcome these production limitations, viticulturists need and desire new robotic solutions to automate agricultural tasks (monitoring, pruning, spraying, and harvesting).

Fig. 1. Steep slope vineyard in the Douro region.

The special Douro's steep slope vineyard features bring a high number of robotic challenges which needs to overcome, namely, robot self-localisation, robot environment perception, environment modelling and decision-making, to reach a fully autonomous and intelligent system [11,15]. The resolution of these robotic challenges, besides improve the robotics technology in agriculture and viticulture, they will reduce the requirement of labour work in the most basic agricultural tasks, such as watering, pruning, harvesting or monitoring. Despite this undeniable impact, agriculture and viticulture robotics research investment does not have as main goal the reduction of human labour, but instead the promotion of a better high-quality product, through the development of new or improved agriculture precision methods [9] that help viticulturist to have better monitoring and control about their cultures.

Between the targets for precision agriculture, Porto wine is a high biotechnology complex product, whose quality level begins at the vineyard and its characteristics are directly related to the interaction with soil, climate and plant physiology. In this scenario, the precision technology brings many advantages to monitor vineyards, measuring the best time for harvesting or detecting plant diseases earlier, ensuring high-quality grapes which results in high-quality wine.

The state-of-the-art for monitoring in precision agriculture can summarise in multi-spectral-satellite, drone imaging and site-specific sensors with pattern recognition and artificial intelligence [14]. Despite this, some experiments point out that the usage of site-specific sensors, also known as site-specific management methods, can bring a closer look at the vine and present more deterministic results [10]. However, this site-specific sensing kind, such as uv-vis-nir or Nuclear Magnetic Resonance (NMR), implies the increment of labour for repetitive tasks or usage of mobile robotics for intelligent sampling along all vineyard. These procedures, beyond a mobile robot, also requires a robotic arm to manipulate the sensor or tool and collect random samples. This goal is not trivial to achieve once the manipulator should be capable of approximate to the grape, through vine foliage, without damage the vine.

Therefore, this work intends to benchmarks the path planners algorithms from Open Manipulation Planning Library (OMPL) Sucan2012. Once viticulture context desires a generic solution for multiple applications, this work selects the hardest path planning case, the pruning task, to evaluate the performance of all path planning algorithms. The generic benchmark platform Moll2015 used, facilitates the evaluation process, granting a broader benchmarking between different poses with different degrees of accessibility difficulty.

This paper is subdivided into five sections. The section 2 presents the related work, mentioning the last developed robots for pruning tasks and a little description of OMPL planners. On section 3, it is presented the chosen approach to solve the stated problem and the follow section analyse the results from different benchmarks. Finally, the conclusions and the future work to improve these results are referred into the last section.

This paper is divided into five sections. Section 2 presents the related work, mentioning the last developed robots for pruning tasks and a small description of OMPL planners. The following section describes the chosen approach to benchmark the algorithms and section 4 analyse the results from the different performance tests. Finally, the last section refers to some conclusions and the future work to improve the reached results.

2 Related Work

Pruning is a typical task for some kind of trees. These tasks may vary with the species kind, the age or the aim for the plant. Besides consume some time, pruning trees also require some specific decision-making knowledge, which does it very attractive in terms of robotics research activities.

In the last few years, researchers have been proposing new robotic solution for pruning. Due to this job, there already are some commercial products, although far of being the ideal solution to this task. Vision Robotics Corporation developed one of these systems. They produced an intelligent system [8], pulled for a tractor, with two robotic arms with scissors which operate inside a light controlled environment.

Tom Botterill *et al* [4,13,2] developed a similar decision-making system which uses an artificial intelligence algorithm to select the pruning points, after mapping the vineyard. An end-effector drill assures whole pruning job which consumes about two minutes (similar time consumed through human labour) [2], using the RRTConnect path planning algorithm.

To urge better research for agricultural robotics, Bac *et al.* [1] wrote a broad survey about robotics developments for pruning and harvesting tasks. Besides presenting the current researching state in this area, the authors indicate the subsequent improvement steps through four future challenges for R&D that may positively trend in performance, to successfully implement harvesting and pruning robots in practice:

Simplify the task – this challenge relates to the workspace design and proposes the development of a modified cultivation system (such as the implementation of the high-wire cultivation system), cultivar selection and breeding and/or implementation of supportive systems.

Enhancing the robot – the integration of sensors system with the world model is the proposed line to achieve the robot enhancement, through reasoning, adaptation and learning capabilities, collaborative robotics, specialised robotics or alternative robot designs.

Defining requirements and measuring performance – this challenge urges for deep testing procedures through well-defined requirements with specific performance indicators and tests. The robots must be tested under a wide range of conditions.

Considering additional requirements for successful implementation – besides the features of the robot, the designed solution should achieve growers and society. So, this should be economically feasible, safe and match the logistics processes.

Considering the research above, there are several challenges to overcome, such as perception or path planning. Concerning to the path planning problem, there are numerous solutions capable of solving this issue. Developing optimisation metrics and considering planner features allows the best calibration parameters reachability. Some typically considered metrics are the trajectory length, execution time, success rate or computational complexity. Additionally, grant the online or offline planning mode or the resolution kind, such as if the planner if complete, complete in resolution or probabilistic complete is also frequent.

There are many path planning algorithms, most of them grouped into generic libraries, such as STOMP [7], CHOMP [17], SBLP or OMPL [16]. OMPL is the most accepted motion planning library by MoveIt! community and the best integrated into this platform. So, the following work it will be just focused in this library.

There are many path planning algorithms which vary with approaching strategy or solving methodology. Due to these features, STOMP [7], CHOMP [17], SBPL[3] and OMPL [16] are generic libraries which intends to group most of these planners. Inside MoveIt! community, OMPL is the most used and the best-integrated motion planning library. So, the following work focuses on the performance of the planners from this library.

[3] `http://http://www.sbpl.net/`

2.1 Open Motion Planning Library

The Open Motion Planning Library (OMPL) [16] contains an implementation of path planning algorithms of a sample-based motion planning kind. It is possible to divide this library into two different categories, geometric-based planners and control-based planners, where the planners from the first group only regard to the geometric and kinematics features and the planners from the second category also consider some dynamic restrictions such like the velocity or the acceleration.

Inside geometric-based planners, it is possible to find single-query planners and multi-query planners. Single-query planners execute the tasks of roadmap creation and path search sequentially and contain planners from RRT, EST and KPIECE family, and STRIDE, PDST, FMT* and BFMT* planners. Otherwise, multi-query planner executes both tasks simultaneously and group planners from PRM and SPARS family. This category also groups a new set of optimisation planners which are variants of the first algorithms, always ensuring the shortest path.

Finally, the control-based planners contain some of the previous planners such as RRT, SST, EST, KPIECE, PDST, Syclop and LTLPlanner, that are capable of manage dynamics constraints.

3 Benchmark Methodology

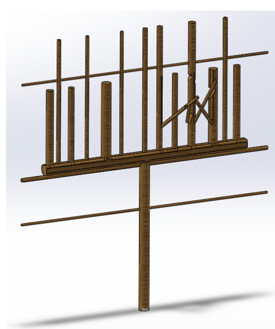


Fig. 2. Vine model to algorithms benchmarking

For the solution under development, there are two ultimate goals. Firstly, intends to touch randomly dispersed grapes along a vineyard with a specific-designed sensor. After, aims to feature the robotic arm with pruning capabilities in real environment conditions. Due to the complexity of operation of robotic arms and the high-cluttered environment, path planning computation is not a trivial task. So, regarding these issues, the next sections plan to approach a benchmarking strategy for OMPL path planners, searching for a robust and efficient path planner.

As referred in section 2, there are several metrics possible to consider. For this case study, the success rate, the planning time, the path length and the path clearance were the most significant features to serialise and select the best performance planners.

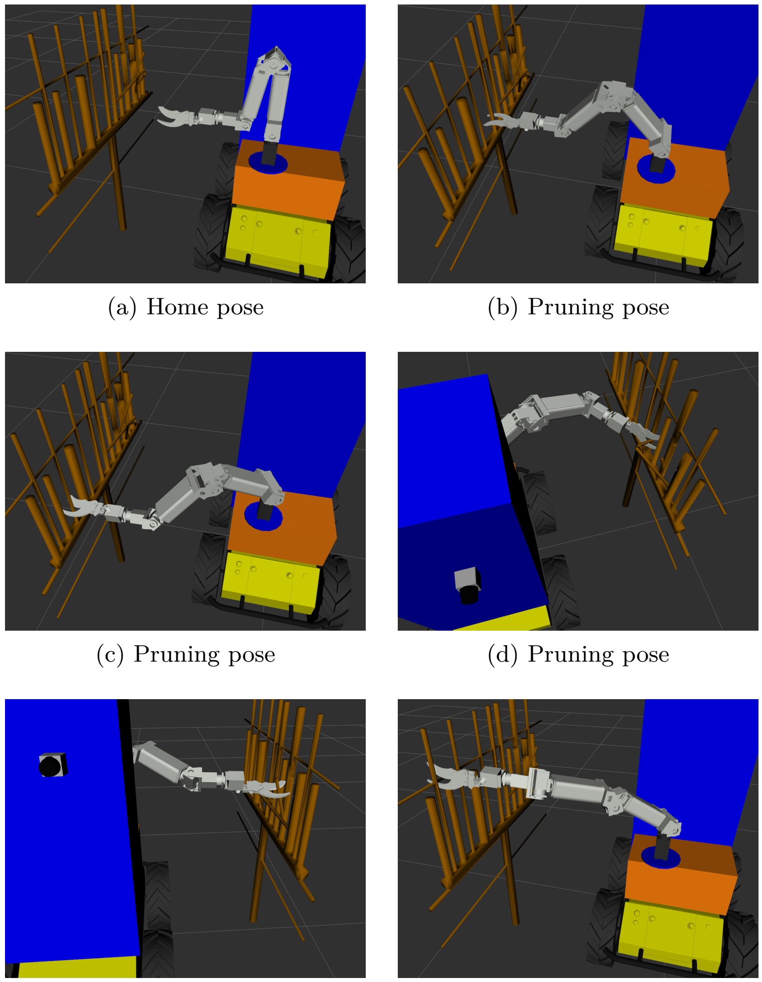
To accomplish the aim of benchmarking the planners for a vine pruning problem, the AgRob v16 robot (Fig. 3) with a simplified model of a vine tree compose the simulated scenario (Fig. 3b). The AgRob v16 robot [11] is a modular mobile robot designed to navigate and manipulate inside Douro's vineyard, sustaining its complexities. At the rear of the robot, there is a lightweight manipulator, the Robotis Manipulator-H, with about 6 kg and a maximum payload of 3 kg. It has 6 DoF and reaches about 633 mm with repeatability of ±0.05 mm. Each joint can move 180^o/s, due to its Robotis Dynamixel servos.

(a) Real mobile robot (b) Simulated mobile robot

Fig. 3. AgRob v16 using a Robotis Manipulator-H arm in (a) real and (b) and simulated environments

An automatic generalised platform [3,12] benchmarked all the path planners at the simulated environment of Fig. 2. Attempting to broad the benchmarking process to evaluate algorithms robustness, the benchmarking platform computed each path planning algorithm between the home pose (Fig. 4a) and each pruning pose (Fig.4b to 4f) and between pruning poses, considering both directions. The selected pruning poses attempts to have different degrees of the accessibility difficulty inside the manipulator workspace, where the poses from Fig. 4b and 4f should be the easiest to reach, the poses from Fig. 4d and 4e the hardest and Fig. 4c the middle-level reachability difficulty. The option for a between two poses path planning instead of a full path planning allows a shortage of the planning time, focusing the computation effort on smaller paths. On future work, it is also possible to parallelise the path planning algorithm with other current tasks, such as grasping or punning.

To solve the path planning problem, all the planners have controllable parameters. Some of them are transverse to all the planners, such as the planning



(a) Home pose (b) Pruning pose

(c) Pruning pose (d) Pruning pose

(e) Pruning pose (f) Pruning pose

Fig. 4. Poses to benchmark. (a) Standard initial pose. (b-f) Selected pruning points

timeout and the Longest Valid Segmentation Fraction (LVSF), while others are specific to the planner or planners family. Once some planners trends to reach always the maximum planning time, namely the planners from multi-query family, it was considered 5s as the maximum supportable waiting time to plan in real environment conditions. Additionally, it was studied the influence of planning timeout and Longest Valid Segmentation Fraction (LVSF) variation in the solution success rate. Since it is intended to perform planners with different features with different and specific controlling parameters, in this first approach, these values were set up with the standard values from the OMPL MoveIt! tutorials[4].

4 Planners Benchmark and Discussion

Path planning algorithms from OMPL library do not assure the same trajectory for the same pair of poses in each running, due to its probabilistic nature. Because of that, planners benchmarking is required to measure its performance for the desired task. All planners performed ten times between each pair of poses of Fig. 3, respecting the Fig. 5, 6 and 7 contain the graphics that illustrate the total path planners success rate between all pairs of points. Comparing these three figures, it is noticeable differences between them.

Observing the graphic of Fig. 5, BiTTR is the best performing algorithm. However, due to its low success rate, less than 40%, this solution cannot be accepted as reliable. Therefore, it is possible to increase the LVSF (which bringing some precision and convergence difficulties) or increase the planning timeout, which seems the best solution.

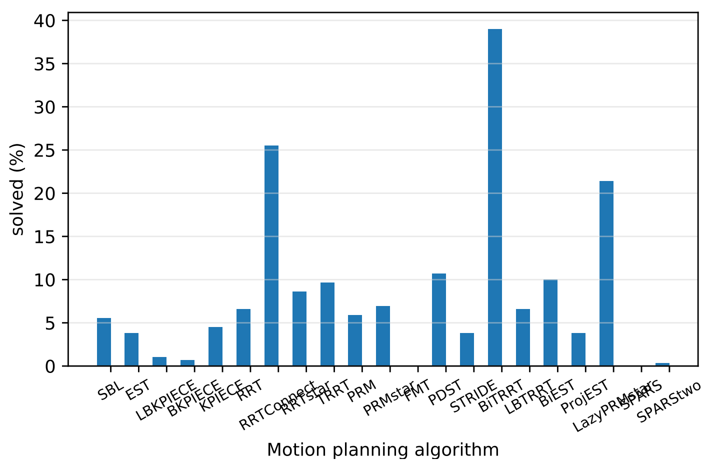


Fig. 5. Success rate of path planners for LVSF = 5 mm and timeout = 2.5 s

Consequently, the graphics of Fig. 6 and 7 show the clear advantage of increasing the available planning time, even decreasing slightly the LVSF. However, besides the overall success rate improvement when only reducing the LVSF (Fig. 6), some planners, as SPARS or SPARStwo, cannot still reach 10% success rate. On the other hand, LBKPIECE and BiTRRT seem to be near perfect solutions. So, considering a success rate higher than 80%, SBL, LBKPIECE,

[4] `https://github.com/ros-planning/panda_moveit_config`

RRTConnect and BiTRRT are the most accepted path planners to be implemented for the final solution.

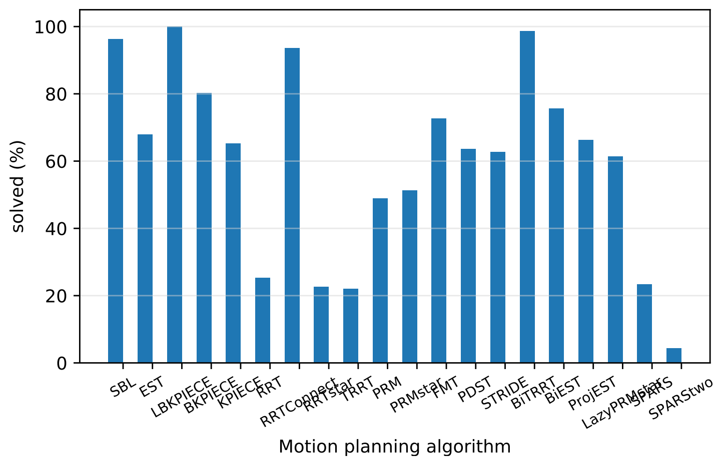


Fig. 6. Success rate of path planners for LVSF = 5 mm and timeout = 5 s

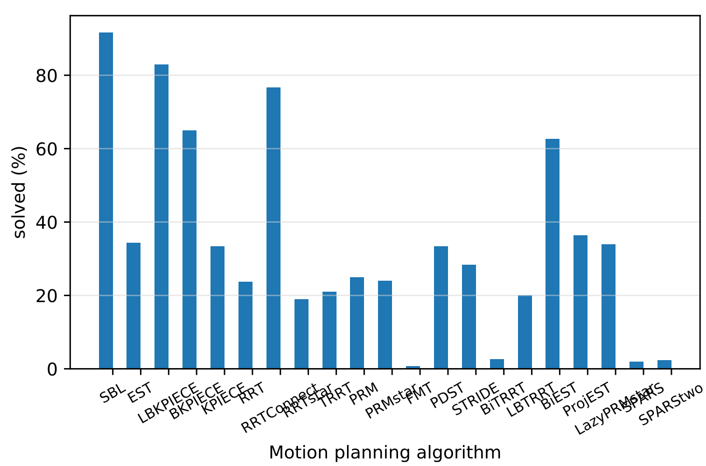
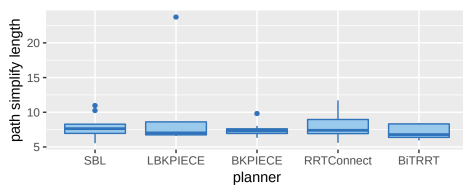


Fig. 7. Success rate of path planners for LVSF = 1 mm and timeout = 5 s

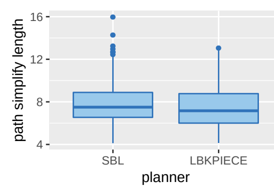
The third approach, observing the success rate when reducing the LVSF to 1 mm (Fig. 7), shows that, as expected, there is an overall deterioration of the planners' performance. However, there are still some remarkable planners such as SBL or LBKPIECE, whose performance keep higher than 80%.

Because of the probabilistic feature of these planners, the path reached for each planner may fluctuate thoughtfully. Therefore, it is also important to analyse the length (Fig. 8) and the clearance (Fig. 9) average and standard deviation for each planner. To simplify this study, just the best performing planners will be considered.

Regarding the resulting path length (Fig. 8), the planners under the conditions of Fig. 8a performed better than planners of Fig. 8b. The first ones have a lower average and standard deviation, but higher outliers, mainly SBL and LBKPIECE planners. BKPIECE performed the smallest and the most identical paths. In its turn, Fig. 8b planners have similar conclusions and LBKPIECE performed the best results.



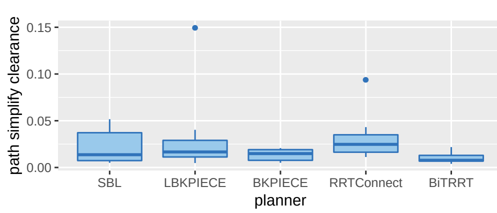
(a) LVSF = 5 mm and Planning timeout 5 s



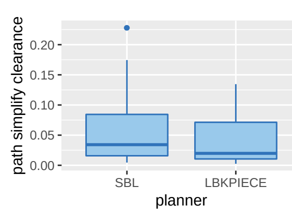
(b) LVSF= 1 mm and Planning timeout 5 s

Fig. 8. Path length

Path clearance metrics attempt to evaluate the highest average and the lowest standard deviation values. Comparing between the results of Fig. 9a and 9b, no advantage is got in select a lower LVSF, the media is identical and the standard deviation is higher. So, focusing on Fig. 9b, the results are still similar and the best results are performed by RRTConnect.



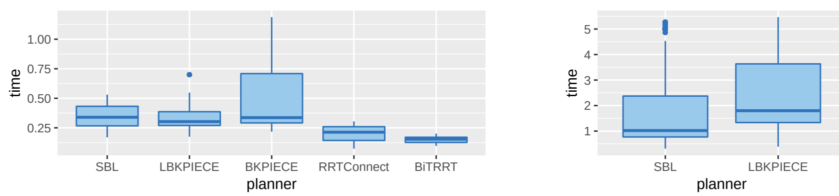
(a) LVSF = 5 mm and Planning timeout 5 s



(b) LVSF= 1 mm and Planning timeout 5 s

Fig. 9. Path clearance

Looking at the same aspects of the previous analysis, SBL seems to perform better than LBKPIECE, on the approach of Fig. 10b. However, the high rate of outliers rejects this conclusion, once they could be harmful to a stable and robust system. On the other hand, in Fig. 10a, BiTRRT has the best performing time and consumes less than 0.25 s to compute the path. Its high standard deviation value assures a high repeatability rate.



(a) LVSF = 5 mm and Planning timeout 5 s

(b) LVSF= 1 mm and Planning timeout 5 s

Fig. 10. Total planning time

Attending the previous discussion, and prioritising measurements as success rate, planning time, path length and path clearance, BiTRRT has the best performance. However, these conclusions should not be fixed, once that are still some planner specific parameter that should also be benchmarked to improve got results.

5 Conclusions

One of the problems faced with the open motion planning library [16] is the probabilistic nature of its planners. Because of that, there is not any assurance that planner founds the same or a similar path in each run for the same pair of poses. Regardless, the studied approach tries to minimise this problem, measuring path planners success rate and full planning and simplification time, path length and path clearance average and standard deviation. Therefore, attending got results, it could be concluded that no advantage is found in using the smallest longest valid segmentation fraction, once the path clearance and length and the success rate worsen. So for this case, it is satisfiable to choose general parameters with 5 mm for the longest valid segmentation fraction (LVSF) and 5 s for the maximum planning time. Inside these conditions and regarding planners performance, considering the classification order of importance of the highest success rate, the lowest planning time, the lowest path length and the highest path clearance, it is reasonable to select BiTRRT [5] as the best path planning algorithm for the proposed problem and improve it in the future.

Considering this benchmarking work, in the future, the planners with the best performance, namely BiTRRT, SBL, LBKPIECE and RRTConnect, should be re-tested, varying their specific parameters. In future work, it should also be explored in detail each planner specific parameters and implemented a solution of OMPL and CHOMP planning, using OMPL as a pre-processing algorithm. Besides that, to optimise the planning time, it should be explored the algorithm parallelisation approaches to reach a better time performance. Another solution is to use a more stable and predictable solution (non-probabilistic planners) through SBPL (Search-Based Planners Library), that contains many algorithms such as A* based or Dijkstra.

This benchmark work helps the reader to understand the limitations of each method and when to use them.

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